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Localized Fire Extinguishing System (LFES): Low Pressure Carbon Dioxide Agent Tests (Horn and Projection Nozzles) with Large and Small Machinery Mockups

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16. Abstract

Two trends in merchant vessel design have generated interest in the localized fire extinguishing system (LFES) concept: the increasing volumes of machinery spaces aboard the larger vessels, and the greater amounts of automation being incorporated int[illegible] essels of all sizes. This report describes fire tests with two mockups of machinery space equipment: a small semi-enclosed machinery with an internal fire and a main propulsion unit with an external fire. In both mockups, the fuel was Number 2 fuel oil. The extinguishing system was a low pressure carbon dioxide LFES.

In the small semi-enclosed machinery with an internal fire mockup, tests were conducted with projection nozzles and conventional horn nozzles. The fire was extinghished in seven out of thirteen tests. In one of the unsuccessful tests, the carbon dioxide discharge rate dropped due to either clogging or freeze-up inside the piping.

In the main propulsion unit with an external fire mockup, only projection nozzles were used. The fire was extinguished in four out of nine tests.

LFES using horn nozzles and projection nozzles are a feasible fire protection system. Projection nozzles permit the nozzles to be placed further from the machinery being protected. This facilitates maintenance and inspection of the machinery.

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METRIC CONVERSION FACTORS

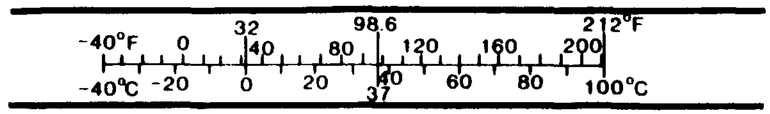
Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (WEIGHT)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (EXACT)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in = 2.54 (exactly)

Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (WEIGHT)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	0.125	cups	c
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (EXACT)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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1.0 INTRODUCTION

The Coast Guard's interest in the localized fire extinguishing system (LFES) concept for machinery spaces arises from two current trends in merchant ship design: increasing machinery space volumes aboard the larger vessels, and the greater amount of automation being incorporated into ships of all sizes.

Present regulations (Reference 1) require that machinery spaces be protected by a large-capacity total flooding system capable of producing an extinguishing concentration throughout the entire space. A small number of portable and semi-portable extinguishers are also required; these are intended for dealing with very small fires.

With the LFES concept, areas or equipment identified as especially fire-prone can be protected by localized extinguishing systems specifically tailored to meet their individual requirements. In the event of a fire involving the protected item, the LFES can then be activated instead of discharging the entire total flooding system. The LFES can produce an extinguishing concentration around the fire more quickly (while using less agent) than the total flooding system.

2.0 OBJECTIVE

The objective of this project was to determine what data are necessary to develop a reasonable performance test for localized fire extinguishing systems in machinery spaces.

3.0 DESCRIPTION OF WORK

3.1 Overall Technical Approach

The tests were conducted on the First Platform deck of the test vessel MAYO LYKES, located at the U.S. Coast Guard Fire and Safety Test Detachment in Mobile, Alabama.

Two groups of tests were included in this series: "S" tests using a mockup that simulated a relatively compact semi-enclosed piece of equipment with an internal fire, and "L" tests which used a larger mockup simulating part of a main propulsion diesel engine.

In this test series, low pressure carbon dioxide (CO_2) was used as the extinguishing agent for simulated machinery space fires involving two different types of equipment. Two types of discharge nozzles were used: conventional "horn" nozzles and projection nozzles, which are capable of directing a more concentrated stream of CO_2 directly onto the protected equipment from a significantly greater horizontal distance.

The carbon dioxide system included a large low pressure carbon dioxide storage tank previously installed on the Boat Deck of the midship structure of the test vessel. A fire extinguishing system manufacturer provided engineering assistance in selecting the CO_2 discharge nozzles and the design of the piping system between the storage tank and the discharge nozzles.

The scope of the test series did not permit optimization of the CO_2 system design; instead the intent was to construct a system that could be considered representative in terms of piping arrangement and nozzle positions.

3.2 Tests on Small Equipment Mockup

3.2.1 Technical Approach

Tests were designed to investigate the use of a localized extinguishing system for protection of small to medium size machinery space equipment. An equipment mockup was placed on an open support frame five feet above the deck of the test compartment. The support frame was located in an area with no nearby enclosures or bulkheads which would tend to hold the extinguishing agent and thereby enhance its effectiveness. This arrangement was intended to simulate the worst case regarding retention of the extinguishing agent around the protected equipment.

The CO_2 system piping was arranged so that both conventional horn nozzles and projection nozzles could be tested at distances ranging from five feet to twenty feet from the mockup.

Number 2 fuel oil was used as the test fuel. A measured amount was placed in small pans inside the mockup components.

3.2.2 Description of Mockup

The small equipment mockup consisted of two sheet metal cylinders, each two feet in diameter and three feet long. The cylinders were mounted end-to-end, one foot apart. They were open at the bottom (over the lower 120 degrees of their circumference) and had several large ventilation openings in the side, top and end areas. The cylinders were fitted with base brackets which rested in a shallow catch pan placed on top of the support frame. The arrangement of the mockup is shown in Figures A-1 through A-5 of Appendix A.

3.2.3 Instrumentation

Instrumentation for these tests included the following types of sensors:

Thermocouples were installed inside and outside the mockup cylinders, so that the intensity of the test fires could be compared. Thermocouples inside the cylinders were also used to determine extinguishment times, since smoke and CO_2 streams usually block the video cameras' view of any flames inside the cylinders.

Gas analyzers (for carbon dioxide and oxygen) were used to measure gas concentrations at eight separate points in and around the mockup cylinders. Carbon dioxide concentrations were measured inside and outside the cylinders to compare characteristics and effectiveness of the individual test CO_2 discharges. Gas concentrations at other points in the test compartment were monitored after the tests to determine when personnel could safely enter the test compartment.

Instrumentation related to the CO_2 system included pressure transducers at four locations inside the discharge line between the CO_2 storage tank and the nozzles, a position indicator for the CO_2 discharge valve near the storage tank, and a load cell measuring total weight of the tank and its contents. Data from these sensors were used to determine the amount of CO_2 discharged in each test, as well as the discharge rate.

Several bidirectional air flow probes were installed in the vicinity of the mockup. The primary purpose of these probes was to indicate any unusual amount of circulation around the mockup that could interfere with extinguishment by dissipating the carbon dioxide agent. The probes also provided a means for assessing whether ambient wind strength or direction could have a significant effect on test results by increasing air circulation inside the test compartment.

Wind speed and direction were measured outside the ship during all tests.

A list of individual instrumentation data channels is contained in Appendix A.

3.2.4 Test Procedures

For each test, a measured amount of Number 2 fuel oil was poured into the fuel pans in each mockup cylinder. (For test S01A, one gallon of fuel was used in each cylinder; for all subsequent tests the amount was 0.5 gallons per cylinder.) The fuel was ignited manually, using a propane torch. After the desired preburn period, the carbon dioxide discharge valve was opened and a predetermined amount of CO_2 was allowed to flow from the storage tank. The readout from the CO_2 storage tank load cell (Channel 73) was used to time the closing of the discharge valve. In those cases where the test fires persisted after the CO_2 discharge, they were allowed to burn themselves out. Post-fire entry to the test compartment was delayed until the area could be ventilated to remove smoke and CO_2 and reintroduce normal levels of oxygen.

This series of 13 tests involved the following controlled variables:

Agent discharge nozzle arrangement:

Two horn nozzles 10 feet from mockup: 1 test
Two horn nozzles 5 feet from mockup: 4 tests
One horn nozzle 5 feet from mockup: 1 test
One projection nozzle 20 feet from mockup: 2 tests
One projection nozzle 10 feet from mockup: 5 tests

Ventilation conditions:

Ventilated (hatch covers removed): 2 tests
Non-ventilated: 11 tests

Preburn time:

From 67 to 118 seconds
(67-81 seconds: 7 tests; 97-118 seconds: 6 tests)

Amount of CO_2 discharged:

From 240 to 830 pounds
(Under 300 lbs: 2 tests; 300-500 lbs: 6 tests; above 500 lbs: 5 tests)

Average rate of CO_2 discharge:

From 2 to 20 pounds per second
(Under 2 lb/sec: 6 tests; from 5 to 10 lb/sec: 5 tests over 10 lb/sec: 2 tests)

3.2.5 Results

Table 3.2.5.1 shows the conditions that apply to each individual test. In the table, the tests are grouped according to the results of the test; e.g., "Fires Extinguished - Both cylinders."

Representative temperature data plots are contained in Appendix B.

TABLE 3.2.5.1 TESTS ON SMALL EQUIPMENT MOCKUP

	NOZZLES			TEST FIRE		CO_2 DISCHARGE		EXTINGUISHMENT TIME [4]		
Test Number	Number and Type	Distance from Mockup	Ventilation Conditions	Preburn Time (sec)	Peak Air/Gas Temp. [1]	CO_2 Weight [2]	Valve Open [3] (min/sec)	Average Discharge Rate	Aft Cylinder (min/sec)	Forward Cylinder (min/sec)
Fire Extinguished										
(Both Cylinders)										
SO5A	2 horn	5 ft	Non-Vent	99	645/370°C	515 lb	4:00	2 lb/sec	2:50	1:40
SO6A	2 horn	5 ft	Non-Vent	81	690/425°C	305 lb	2:20	2 lb/sec	3:30	1:45
SO8A	2 horn	5 ft	Non-Vent	78	650/470°C	440 lb	3:00	2 lb/sec	3:10	2:45
SO9A	2 horn	5 ft	Vent	78	645/580°C	380 lb	3:10	2 lb/sec	3:10	2:30
SO2A	1 Proj	20 ft	Non-Vent	118	530/660°C	435 lb	1:20	5 lb/sec	0:50	2:30
SO10A	1 Proj	10 ft	Vent	78	640/515°C	830 lb	0:40	20 lb/sec	0:40	0:40
SO11A	1 Proj	10 ft	Non-Vent	71	640/350°C	615 lb	0:40	15 lb/sec	0:50	0:30
(Aft Cylinder Only)										
SO2B	1 Proj	10 ft	Non-Vent	114	695/690°C	340 lb	0:40	9 lb/sec	0:50	(12:00)
SO2D	1 Proj	10 ft	Non-Vent	109	690/740°C	570 lb	1:00	10 lb/sec	0:50	--
SO3A	1 Proj	10 ft	Non-Vent	108	620/710°C	290 lb	0:30	10 lb/sec	1:10	--
(Forward Cylinder Only)										
SO1A	1 Proj	20 ft	Non-Vent	67	690/710°C	520 lb	0:50	10 lb/sec	--	--
Fire Temporarily Suppressed										
SO7A	1 Horn	5 ft	Non-Vent	67	675/490°C	240 lb	1:40	2 lb/sec	--	--
Fires Unsuppressed										
SO4A	2 Horn	10 ft	Non-Vent	97	695/750°C	425 lb	3:50	2 lb/sec	--	--

NOTES:

[1] From Channel 0 (aft cylinder) and Channel 1 (forward cylinder) data plots.

[2] From Channel 73 data plots.

[3] From Channel 87 plots.

[4] Time from opening of discharge valve (Channel 87 data plots) to temperature of 100°C (from Channel 0 and Channel 1) data plots.

In the table, the following definitions apply:

<u>Ventilation conditions</u>: "Vent" indicates that the hatch cover sections (on the Main Deck, directly above the mockup area) were removed before the start of the test. Removal of the hatch covers allowed smoke and fire gases to escape easily from the test area, and also encouraged the maximum amount of natural circulation in the vicinity of the fire. This amounts to a worst case in regard to the ability of a given amount of agent to extinguish the test fire, because the circulation not only supplies fresh oxygen to support the fire, but also tends to disperse the agent at the same time. "Non-vent" indicates that the hatch covers were in place during the test.

<u>Preburn time</u>: the period between ignition of the fuel inside the first mockup cylinder and opening of the CO_2 discharge control valve (indicated by the Channel 87 plot).

<u>Peak air/gas temperatures</u>: the highest temperatures indicated by the thermocouples located in the middle of the volumes enclosed by each mockup cylinder. Channel 0 indicated temperature inside the aft cylinder and Channel 1 indicated forward cylinder temperature.

<u>CO_2 weight</u>: weight of CO_2 applied as determined by the difference between mean weight of the CO_2 storage tank before the CO_2 discharge control valve is opened and the steady-state mean weight indicated after fluctuations resulting from valve closure die out. The CO_2 weight is determined from a plot of Channel 73 data.

<u>Valve open</u>: the period between opening and closing of the CO_2 discharge control valve. The elapsed time is determined as the period during which the voltage indicated on the Channel 87 plot is other than zero.

<u>Average discharge rate</u>: the CO_2 weight divided by the valve open time (both of which are defined above).

For the purposes of Table 3.2.5.1, a fire is considered extinguished if the air/gas temperature inside a cylinder (as indicated by the Channel 0 or Channel 1 data plot) drops to 100°C or less after the CO_2 discharge valve is opened. If the temperature drops sharply after the valve is opened, but later rises again, the fire is considered temporarily suppressed. If the CO_2 discharge has little apparent effect, the fire is considered to be unsuppressed.

Table 3.2.5.1 shows that fires were successfully extinguished in both cylinders in seven of the thirteen tests. In four other tests, partial success was achieved: the fire in one of the two mockup cylinders was extinguished.

In one of the remaining tests (S07A), the fires were only temporarily suppressed. Only 240 pounds of CO_2 was discharged; this was the smallest amount of agent used in any test. In the other test (S04A), although 425 pounds of agent were used, the discharge period lasted nearly four minutes. This resulted in the lowest discharge rate observed in the tests. Apparently, the prolonged discharge resulted from partial clogging, or, more likely, freeze-up inside the CO_2 piping.

3.3 Tests on Large Equipment Mockup

3.3.1 Technical Approach

Tests were conducted as a follow-up to a previous test series, which also used low pressure carbon dioxide as the extinguishing agent, as well as the same mockup (Reference 2). In the previous tests, the agent was discharged from an array of six conventional nozzles located close to the mockup. In the tests described in this report, the agent was discharged from two projection nozzles located further away. Test procedures were similar to those used in the earlier test series.

3.3.2 Description of Mockup

The mockup used in these tests was designed to resemble a large piece of machinery space equipment, with extensive vertical surfaces, as well as numerous projections and recesses. Its basic outline resembles a portion of a main propulsion diesel engine. Overall dimensions were 16 feet long by 12 feet high. Arrangement of the mockup is shown in Figures A-6 and A-7 of Appendix A. For the fire tests, two gallons of Number 2 fuel oil were placed in a large fuel pan next to the base of the mockup and ignited manually.

3.3.3 Instrumentation

Instrumentation for tests involving the large mockup was similar to that used for the small mockup (See Section 3.2.3).

The most important of the instrumentation sensors were those located on and around the mid-length portion of the mockup, since this was the area where the test fire flames were the strongest. Temperature readings from thermocouples in this zone were used to compare the intensities of the test fires, and to determine extinguishment times.

An instrumentation list is contained in Appendix A.

3.3.4 Test Procedures

For the fire tests, Number 2 diesel fuel oil was placed in a large fuel pan next to the base of the mockup. A small amount of mineral spirits was added to promote rapid spread of the fire across the fuel pan. The test fires were ignited manually with a torch. Thirty seconds after ignition, the large mockup fuel system began pouring additional fuel oil onto the center section of the mockup through a transverse perforated pipe. After a 2-minute burn time, the flow of fuel was shut off, the CO_2 system was activated, and a predetermined amount of CO_2 was allowed to flow from the storage tank. The readout from the CO_2 storage tank load cell (Channel 73) was used to time the closing of the discharge valve. In those cases where the test fires persisted after the CO_2 discharge, they were allowed to burn themselves out. Post-fire entry to the test compartment was delayed until the area could be ventilated to remove smoke and CO_2 and reintroduce normal levels of oxygen.

As in the small mockup tests, ventilation conditions were varied by removing hatch cover sections one deck level above the mockup for some of the tests.

Most of the fire tests were run with projection nozzles positioned 20 feet away from the mockup. Two tests were run at a nozzle distance of 10 feet.

3.3.5 Results

Nine fire tests were completed, as shown in Table 3.3.5.1.

In four cases the fire was completely extinguished, with extinguishment times ranging from 50 seconds to almost six minutes.

In three other cases the fire on the upper part of the mockup was extinguished, but the fire in the fuel pan at the base of the mockup was only temporarily affected, and continued to burn for several minutes afterward.

In two cases, the fire on the upper part of the mockup and the fire at the base of the mockup were only temporarily suppressed, and continued to burn until most of the fuel was consumed.

Representative temperature data plots are contained in Appendix B.

Peak temperatures ranged from 840 to 950°C near the lower part of the mockup and from 730 to 890°C near the upper part. In all nine fire tests, the flames were at least temporarily suppressed, even when as little as 215 pounds of CO_2 was discharged.

TABLE 3.3.5.1 TESTS ON LARGE EQUIPMENT MOCKUP

NOZZLES			TEST FIRE			CO_2 DISCHARGE			EXTINGUISHMENT TIME [4]	
Test Number	No. & Type	Distance from Mockup	Ventilation Conditions	Preburn Time (min/sec)	Peak Air/Gas Temp. [1]	CO_2 Weight [2]	Valve] Open [3] (min/sec)	Average Discharge Rate	Top of Mockup (min/sec)	Bottom of Mockup (min/sec)
Fire extinguished										
LO3B	2 proj	20 ft	Vent	4:00	760/850°C	600 lb	0:50	12 lb/sec	2:40	0:50
LO4A	2 proj	20 ft	Non-Vent	3:45	830/860°C	600 lb	0:40	15 lb/sec	4:00	1:00
LO6A	2 proj	20 ft	Vent	3:55	880/930°C	1050 lb	0:60	18 lb/sec	5:50	0:50
LO6D	2 proj	10 ft	Vent	4:00	801/840°C	1000 lb	0:50	20 lb/sec	0:40	0:50
Fire extinguished on top, re-flash at bottom										
LO3A	2 proj	20 ft	Vent	4:50	730/880°C	215 lb	0:20	11 lb/sec	0:30	11:00
LO3C	2 proj	20 ft	Vent	4:25	860/880°C	500 lb	0:30	17 lb/sec	3:30	12:00
LO4B	2 proj	20 ft	Non-Vent	3:55	890/910°C	490 lb	0:30	16 lb/sec	5:00	11:30
Fire temporarily suppressed										
LO6B	2 proj	20 ft	Non-Vent	4:10	830/900°C	500 lb	0:30	17 lb/sec	4:00 [5]	16:50 [5]
LO7A	2 proj	10 ft	Vent	4:05	770/950°C	490 lb	0:40	12 lb/sec	8:50 [5]	14:30 [5]
(No fire)										
LO1A	2 proj	20 ft	Non-Vent	---	---	160 lb	[6]	---		
LO5A	2 proj	20 ft	Non-Vent	---	---	520 lb	0:30	17 lb/sec		
LO6C	2 proj	10 ft	Non-Vent	---	---	570 lb	0:30	19 lb/sec		

[1] From Channel 2 (upper part of mockup) and 29 (near base of mockup).

[2] From Channel 73 data plot.

[3] Determined from Channel 87 data plot.

[4] Time from opening of discharge valve (Channel 87 data plot) to temperature of 200°C (from Channel 2 and Channel 29 data plots).

[5] Second extinguishment.

[6] No data.

Seven of the tests were run with the nozzles located 20 feet from the mockup and two tests were run with the nozzles 10 feet away. In one of the tests at 10 feet, approximately 1000 pounds of CO_2 was discharged onto the fire (resulting in extinguishment). In the other test, 500 pounds was discharged and the fire was only temporarily suppressed.

Average discharge rate varied considerably during these tests. The reason for the variation is not known. There was no evidence of freeze-up or clogging inside the CO_2 piping, as was observed during tests with the small equipment mockup.

4.0 DISCUSSION

4.1 Small Equipment Mockup Tests

The results of tests with the small equipment mockup indicate:

- For the combination of nozzle arrangements and mockup configuration that was tested, 400 to 500 pounds of CO_2, applied at an average rate of 2.5 pounds per second, appears adequate for extinguishment of test fires inside both cylinders.
- With a given supply piping system configuration, a single projection nozzle can provide a CO_2 application rate that is two to eight times greater than two horn-type nozzles.
- Projection nozzles can be located at least 20 feet from the protected equipment, and still provide satisfactory protection.
- By design, the projection nozzle produces a more intense stream of agent than the horn nozzle. This stream could cause spattering and spread of an exposed liquid pool fire.
- Freeze-up or mechanical clogging of the discharge nozzles can greatly reduce the agent discharge rate.

4.2 Large Equipment Mockup Tests

The results of the tests with the large equipment mockup indicate:

- The minimum amount of agent that can achieve complete extinguishment is about 600 pounds, discharged at an average rate of 12 to 20 pounds per second using the projection nozzle arrangement described previously. In a previous test series

with the large equipment mockup in which conventional CO_2 horn nozzles were used, it was determined that the minimum amount of agent necessary for consistent, rapid extinguishment was 500 pounds, applied at a rate of about 10 pounds per second (Reference 2).

In comparing results of the two test series, it must be noted that in the earlier tests, the six horn nozzles were placed relatively close to the mockup and arranged so as to provide good coverage over the burning fuel at the midpoint of the mockup, as well as the mockup areas on either side of the fire. This sort of nozzle layout may not always be possible in actual machinery spaces, because of interference with other equipment and piping systems.

If projection nozzles are used instead, they can be installed farther away from the protected equipment. In these tests, 15 to 20 percent more agent was required when two more distant projection nozzles were used. This indicates that one advantage of projection nozzles is the capability of providing a comparable degree of protection in cases where installation of horn nozzles is impractical.

- It appears unlikely that locating the projection nozzles closer than 20 feet from the protected equipment would have a major effect on their performance.

- Ventilation conditions (main deck hatch covers either in place or removed) appear to have little effect on peak flame temperatures in the center of the mockup. The ambient wind velocities averaged two miles per hour or less for six of the nine tests.

5.0 CONCLUSIONS

- Based on the results of these tests with both the small and large equipment mockups, it appears that CO_2 projection nozzles can be useful in machinery space applications, especially where conventional nozzles cannot be placed close to the protected equipment.

- The results of these tests together with those reported in Reference 2 indicate that a performance test for a localized fire

extinguishing system using carbon dioxide should include measurement of the following test parameters during a live fire test of the specified configuration:

(1) Weight loss of carbon dioxide as a function of time.

(2) Air/gas temperature measurements using an array of thermocouples located throughout the fire zone.

(3) Open and closure times for the carbon dioxide actuation valves.

- Additional information which would be useful in interpreting the test results would be the measurement of carbon dioxide and oxygen concentrations in the fire zone.

REFERENCES

1. Code of Federal Regulations, Title 46 - Shipping, Chapter I (Subparts 34.15, 76.15 and 95.15): Coast Guard, Department of Transportation. General Services Administration, 1990.

2. Wolverton, C.D., Jr., Localized Fire Extinguishing System (LFES): Low Pressure Carbon Dioxide Agent Tests With Large Machinery Mockup. U.S. Coast Guard, Marine Fire & Safety Research Division Technical Report No. 052, May 1986.

APPENDIX A

Instrumentation List

The complete list of test instrumentation for the large and small mockups is contained in this appendix. Sensor locations are shown on the accompanying sketches.

APPENDIX A

INSTRUMENTATION

Channel #	Instrument Description	Reference Junction/ serial #	Output Range Eng. Unit	Output Range Volts	Diesel Mockup Location	Motor Mockup Location
0	Thermocouple (Type K)(1)	Channel 47	0 to 1000°C	0 to 0.0415	1ft off upper part	inside aft cylinder
1	Thermocouple (Type K)	Channel 47	0 to 1000°C	0 to 0.0415	1ft off upper part	inside fwd cylinder
2	Thermocouple (Type K)	Channel 47	0 to 1000°C	0 to 0.0415	1ft off upper part	fuel pan
3	Thermocouple (Type K)	Channel 47	0 to 1000°C	0 to 0.0415	1ft off upper part	fuel pan
4	Thermocouple (Type K)	Channel 47	0 to 1000°C	0 to 0.0415	1ft off upper part	fuel pan
5	Thermocouple (Type K)	Channel 47	0 to 1000°C	0 to 0.0415	1ft off shoulder	fuel pan
6	Thermocouple (Type K)	Channel 47	0 to 1000°C	0 to 0.0415	1ft off shoulder	fuel pan
7	Thermocouple (Type K)	Channel 47	0 to 1000°C	0 to 0.0415	1ft off shoulder	outside fwd cylinder
8	Thermocouple (Type K)	Channel 47	0 to 1000°C	0 to 0.0415	1ft off shoulder	outside fwd cylinder
9	Thermocouple (Type K)	Channel 47	0 to 1000°C	0 to 0.0415	1ft off shoulder	outside fwd cylinder
10	Thermocouple (Type K)	Channel 47	0 to 1000°C	0 to 0.0415	1ft off lower slope	inside fwd cylinder
11	Thermocouple (Type K)	Channel 47	0 to 1000°C	0 to 0.0415	1ft off lower slope	inside fwd cylinder
12	Thermocouple (Type K)	Channel 47	0 to 1000°C	0 to 0.0415	1ft off lower slope	spare
13	Thermocouple (Type K)	Channel 47	0 to 1000°C	0 to 0.0415	1ft off lower slope	spare
14	Thermocouple (Type K)	Channel 47	0 to 1000°C	0 to 0.0415	1ft off lower slope	spare
15	Thermocouple (Type K)	Channel 47	0 to 1000°C	0 to 0.0415	on upper slope	outside aft cylinder
16	Thermocouple (Type K)	Channel 47	0 to 1000°C	0 to 0.0415	on upper slope	outside aft cylinder
17	Thermocouple (Type K)	Channel 57	0 to 1000°C	0 to 0.0415	on upper slope	outside aft cylinder
18	Thermocouple (Type K)	Channel 57	0 to 1000°C	0 to 0.0415	on upper slope	inside aft cylinder
19	Thermocouple (Type K)	Channel 57	0 to 1000°C	0 to 0.0415	on upper slope	inside aft cylinder
20	Thermocouple (Type K)	Channel 57	0 to 1000°C	0 to 0.0415	on shoulder point	1ft off aft cylinder
21	Thermocouple (Type K)	Channel 57	0 to 1000°C	0 to 0.0415	on shoulder point	1ft off fwd cylinder
22	Thermocouple (Type K)	Channel 57	0 to 1000°C	0 to 0.0415	on shoulder point	1ft off aft cylinder
23	Thermocouple (Type K)	Channel 57	0 to 1000°C	0 to 0.0415	on shoulder point	1ft off fwd cylinder
24	Thermocouple (Type K)	Channel 57	0 to 1000°C	0 to 0.0415	on shoulder point	between cylinders
25	Thermocouple (Type K)	Channel 57	0 to 1000°C	0 to 0.0415	3 ft above top	1ft aft of aft cylinder
26	Thermocouple (Type K)	Channel 57	0 to 1000°C	0 to 0.0415	3 ft above top	1ft fwd of fwd cylinder
27	Thermocouple (Type K)	Channel 57	0 to 1000°C	0 to 0.0415	3 ft above top	3 ft off aft cylinder
28	Thermocouple (Type K)	Channel 57	0 to 1000°C	0 to 0.0415	above drain pan	3 ft off fwd cylinder
29	Thermocouple (Type K)	Channel 57	0 to 1000°C	0 to 0.0415	above drain pan	3 ft off aft cylinder

INSTRUMENTATION (continued)

Channel #	Instrument Description	Reference Junction/ serial #	Output Range Eng. Unit	Output Range Volts	Diesel Mockup Location	Motor Mockup Location
30	Thermocouple (Type K)	Channel 57	0 to 1000°C	0 to 0.0415	above drain pan	3 ft off fwd cylinder
31	Thermocouple (Type K)	Channel 57	0 to 1000°C	0 to 0.0415	on top of 6 in pipe	3 ft aft of aft cylinder
32	Thermocouple (Type K)	Channel 57	0 to 1000°C	0 to 0.0415	on top of 6 in pipe	3 ft fwd of fwd cylinder
33	Thermocouple (Type K)	Channel 57	0 to 1000°C	0 to 0.0415	under upper heater pad	3 in below bottom of deck beams over aft cylinder
34	Thermocouple (Type K)	Channel 58	0 to 1000°C	0 to 0.0415	under middle heater pad	3 in below bottom of deck beams, over fwd cylinder
35	Thermocouple (Type K)	Channel 58	0 to 1000°C	0 to 0.0415	under lower heater pad	1ft off deck, under aft cylinder
36	Thermocouple (Type K)	Channel 58	0 to 1000°C	0 to 0.0415	spare	1ft off deck under fwd cylinder
37	Thermocouple (Type K)	Channel 58	0 to 1000°C	0 to 0.0415	on 4 in pipe, near CO_2 tank	same as for diesel mockup
38	Thermocouple (Type K)	Channel 58	0 to 1000°C	0 to 0.0415	on 4 in pipe, below main dck	same as for diesel mockup
39	Thermocouple (Type K)	Channel 58	0 to 1000°C	0 to 0.0415	at end of 4 in pipe	same as for diesel mockup
40	Thermocouple (Type K)	Channel 58	0 to 1000°C	0 to 0.0415	near fwd nozzle	near stbd fwd nozzle
41	Thermocouple (Type K)	Channel 58	0 to 1000°C	0 to 0.0415	near aft nozzle	near port fwd nozzle
42	Thermocouple (Type K)	Channel 58	0 to 1000°C	0 to 0.0415	spare	spare
43	Thermocouple (Type K)	Channel 58	0 to 1000°C	0 to 0.0415	inside fuel tank	same as for diesel mockup
44	Thermocouple (Type K)	Channel 58	0 to 1000°C	0 to 0.0415	spare	spare
45	Thermocouple (Type K)	Channel 58	0 to 1000°C	0 to 0.0415	spare	spare
46	Thermocouple (Type K)	Channel 58	0 to 1000°C	0 to 0.0415	spare	spare
47	Thermocouple Ref Junction	Junct. TCH	-10 to 50°C	0.000435 to 0.0022	1st platform deck	same as for diesel mockup
48	Oxygen Analyzer (Sample A)	73-69701-1-1	0 to 25%	0 to 0.005	1ft off shoulder	inside aft cylinder
49	Oxygen Analyzer (Sample B)	74-50059-1-1	0 to 25%	0 to 0.005	1ft off 6 in pipe	18 in off centerline
50	Oxygen Analyzer (Sample C)	74-50059-1-2	0 to 25%	0 to 0.005	2 ft from base	18 in off centerline
51	CO Analyzer (Sample A)		0 to 10%	0 to 0.100	see Channel 48	see Channel 48
52	CO Analyzer (Sample B)		0 to 10%	0 to 0.100	see Channel 49	see Channel 49
53	CO Analyzer (Sample C)		0 to 10%	0 to 0.100	see Channel 50	see Channel 50
54	Oxygen Analyzer	1001637	0 to 25%		to be assigned on site	to be assigned on site
55	Oxygen Analyzer	1001638	0 to 25%		to be assigned on site	to be assigned on site
56	Oxygen Analyzer	1001641	0 to 25%		to be assigned on site	to be assigned on site
57	Thermocouple Ref Junction	Junct. TG5	-10 to 50°C	.000435 to .0022		
58	Thermocouple Ref Junction	Junct. TG6	-10 to 50°C	.000435 to .0022		
59	Unassigned					
60	CO_2 Analyzer (Sample A)	30606	0 to 50%	0 to 0.100	see Channel 48	see Channel 48

INSTRUMENTATION (continued)

Channel #	Instrument Description	Reference Junction/ serial #	Output Range Eng. Unit	Output Range Volts	Diesel Mockup Location	Motor Mockup Location
61	CO_2 Analyzer (Sample B)	31334	0 to 50%	0 to 0.100	see Channel 49	see Channel 49
62	CO_2 Analyzer (Sample C)	31335	0 to 50%	0 to 0.100	see Channel 50	see Channel 50
63	CO_2 Analyzer (Sample D)	34056	0 to 50%	0 to 0.100	5 ft from base	18 in off deck, 4 ft from hull
64	CO_2 Analyzer (Sample E)	34057	0 to 50%	0 to 0.100	5 ft from base	18 in off deck, 4 ft from (fwd)
65	CO_2 Analyzer (Sample F)	34059	0 to 50%	0 to 0.100	5 ft from base	18 in off deck, below cylinders
66	CO_2 Analyzer (Sample G)	34061	0 to 50%	0 to 0.100	10 ft from base	above cylinders
67	CO_2 Analyzer (Sample H)	34062	0 to 50%	0 to 0.100	10 ft from base	spare
68	CO_2 Analyzer (Sample I)	34063	0 to 25%	0 to 0.100	spare	spare
69	CO_2 pressure transducer	84340	0 to 500 psi	0 to 0.100	in 4 in pipe, near CO_2 tank	same as for diesel mockup
70	CO_2 pressure transducer	84391	0 to 500 psi	0 to 0.100	at end of 4 in pipe	same as for diesel mockup
71	CO_2 pressure transducer	84392	0 to 500 psi	0 to 0.100	near fwd nozzle	near stbd fwd nozzle
72	CO_2 pressure transducer	84393	0 to 500 psi	0 to 0.100	near aft nozzle	near port fwd nozzle
73	Load Cell	1520	0 to 20000lb	0 to 0.100	CO_2 tank (boat deck)	same as for diesel mockup
74	Bi-Directional Flow Probe		-3750 fpm to	-10		
			+3750 fpm	+10	3 ft off shoulder (fwd)	near fuel pan
75	Bi-Directional Flow Probe		-3750 fpm to	-10		
			+3750 fpm	+10	3 ft off shoulder (fwd)	near fuel pan
76	Bi-Directional Flow Probe		-3750 fpm to	-10		
			+3750 fpm	+10	3 ft off shoulder (fwd)	over aft cylinder
77	Bi-Directional Flow Probe		-3750 fpm to	-10		
			+3750 fpm	+10	3 ft off shoulder	over fwd cylinder
78	Bi-Directional Flow Probe		-3750 fpm to	-10		
			+3750 fpm	+10	18 in off shoulder (fore/aft)	above mockup, to stbd
79	Bi-Directional Flow Probe		-3750 fpm to	-10		
			+3750 fpm	+10	spare	above mockup, to stbd
80	Bi-Directional Flow Probe		-3750 fpm to	-10		
			+3750 fpm	+10	spare	spare
81	Wind Direction Indicator	04401A-D	North 0°		to be assigned on site	same as for Diesel Mockup
82	Oxygen Analyzer	34064	0 - 25%		to be assigned on site	same as for Diesel Mockup
83	Oxygen Analyzer	35065	0 - 25%		to be assigned on site	same as for Diesel Mockup
84	Wind Velocity Meter	04401A-I	0 - 100 mph		to be assigned on site	same as for Diesel Mockup

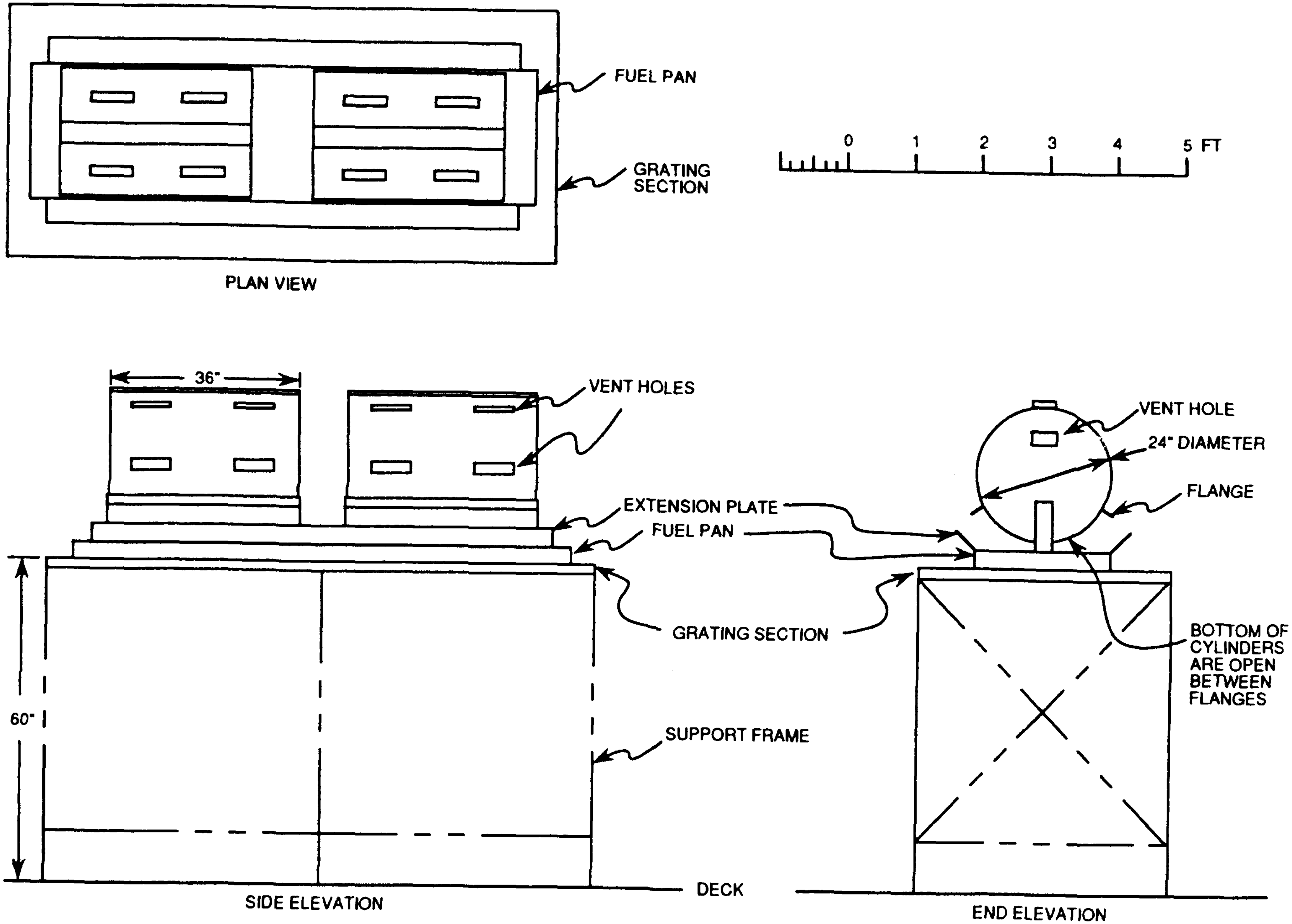

FIGURE A-1 Motor Mockup Arrangement

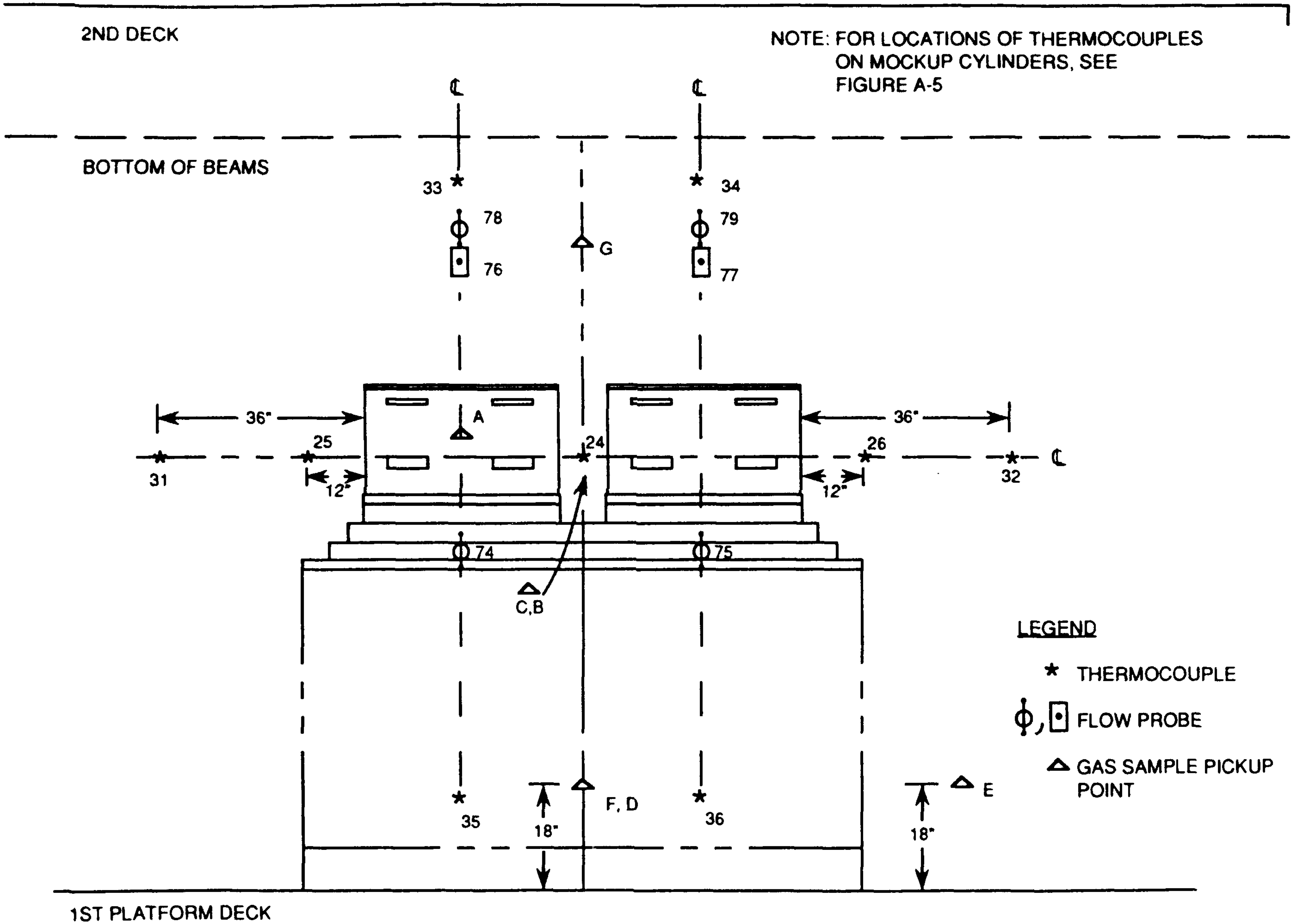

FIGURE A-2 Motor Mockup Instrumentation (Side Elevation)

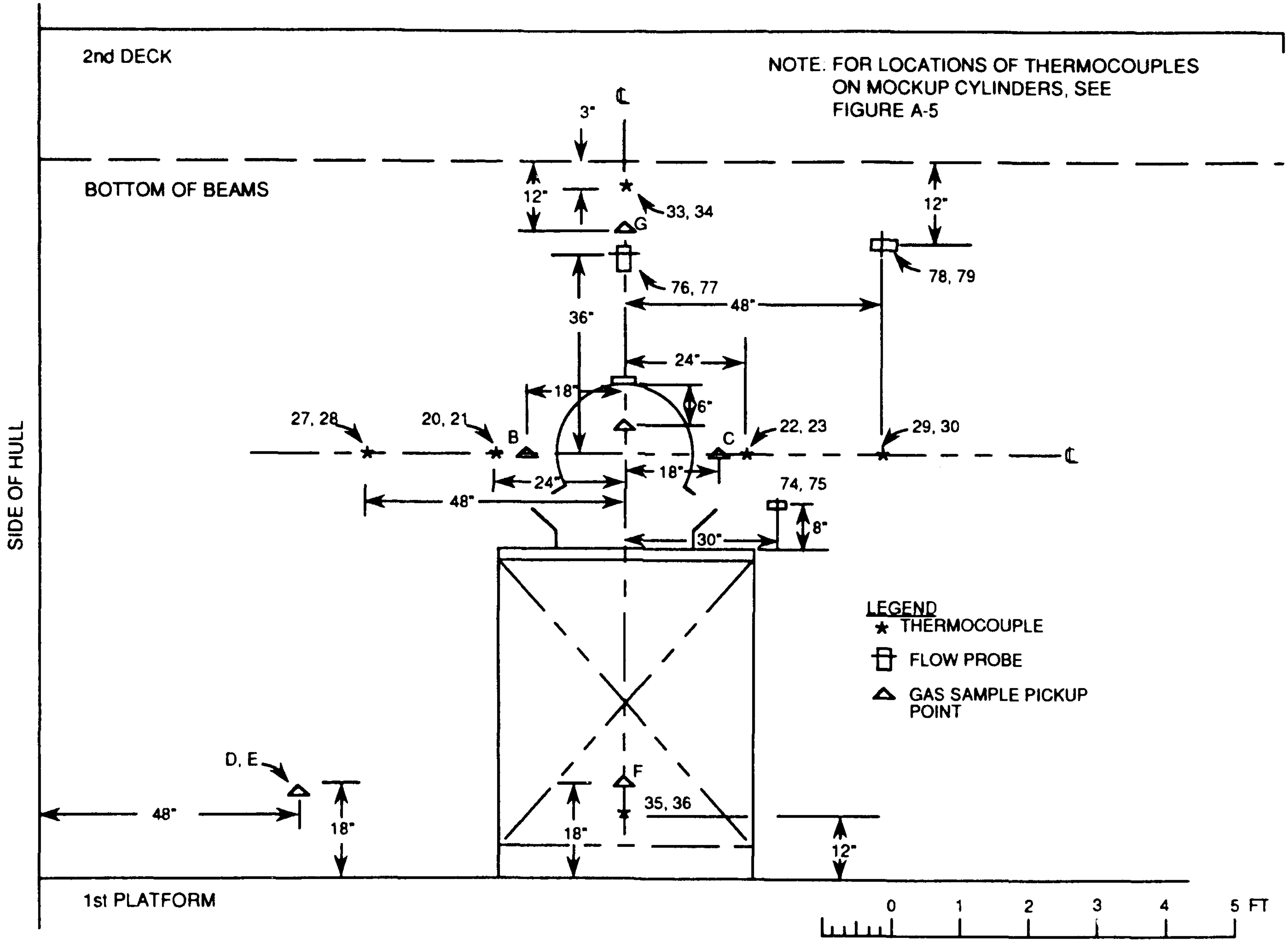

FIGURE A-3 Motor Mockup Instrumentation (End Elevation)

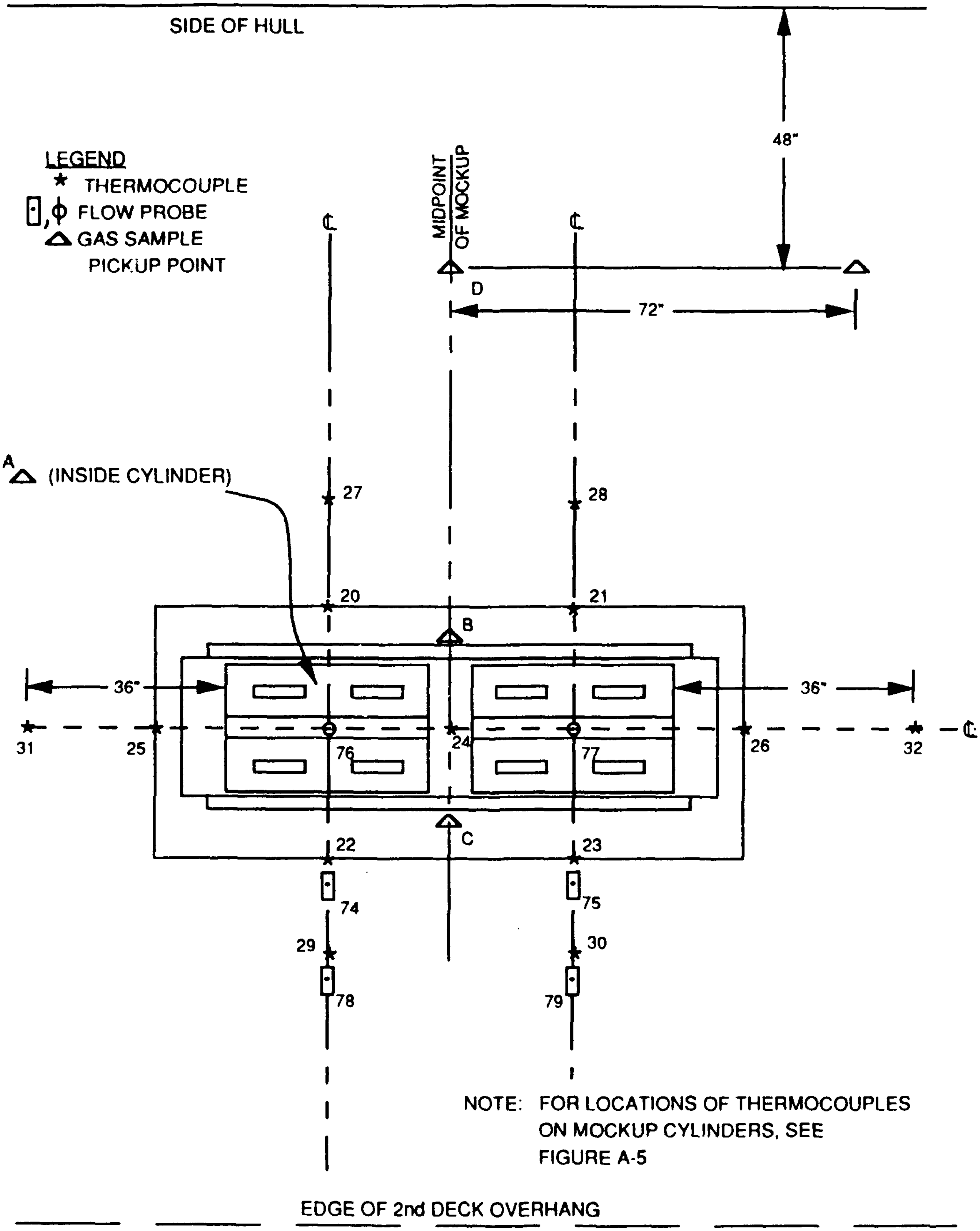

FIGURE A-4 Motor Mockup Instrumentation (Plan View)

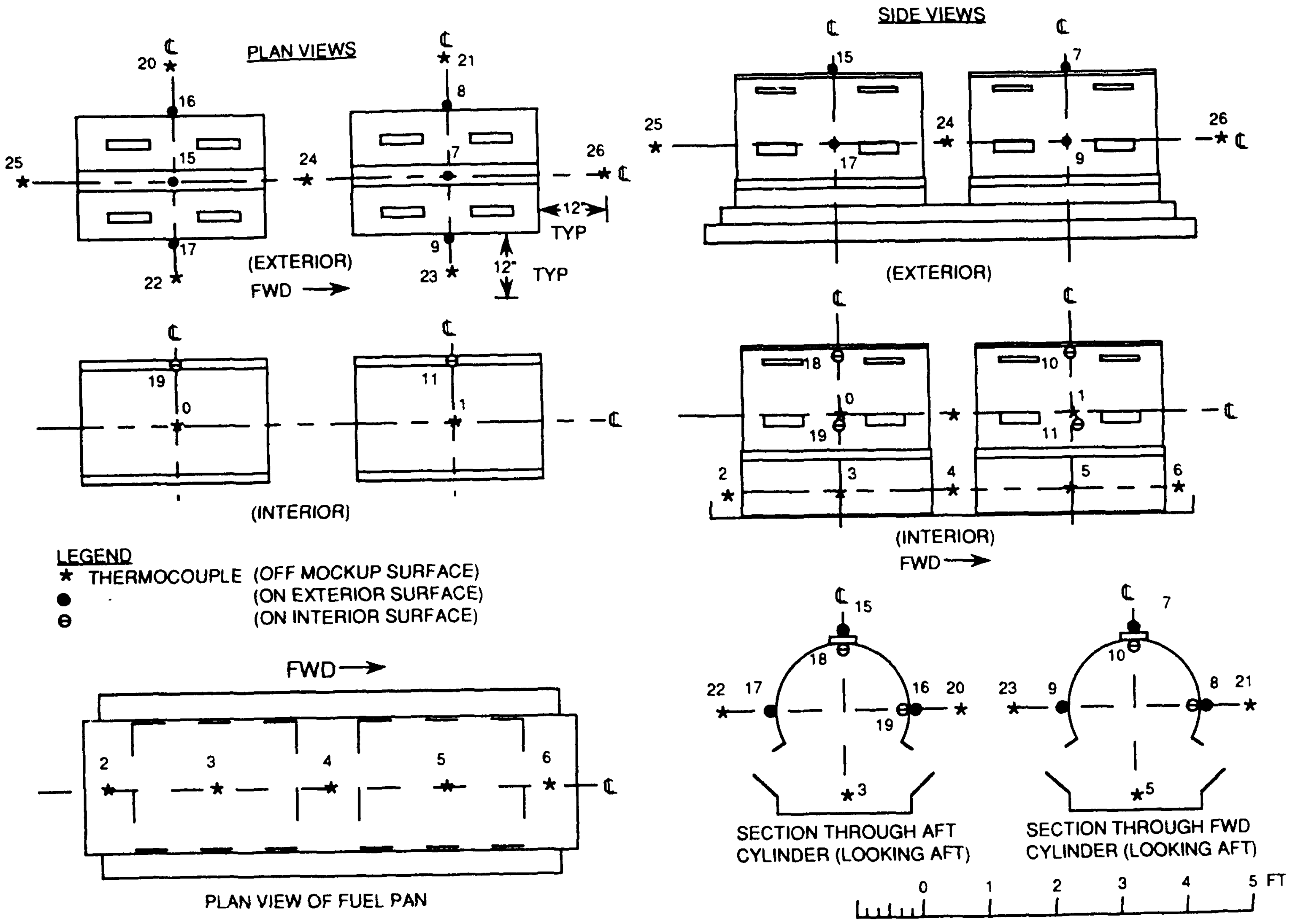

FIGURE A-5 Motor Mockup Thermocouple Locations Near Cylinders

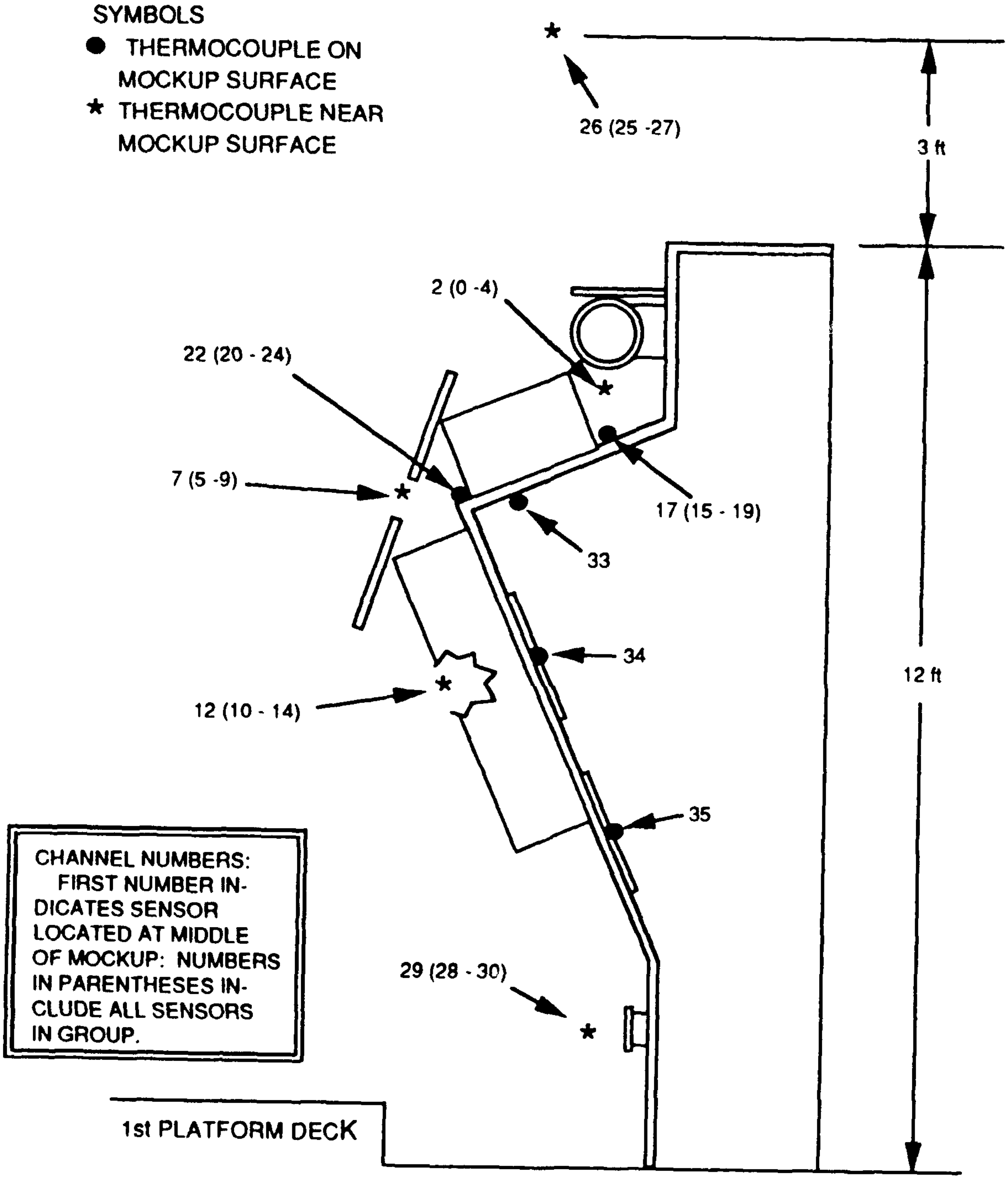

FIGURE A-6 Diesel Mockup Temperature Instrumentation (End View)

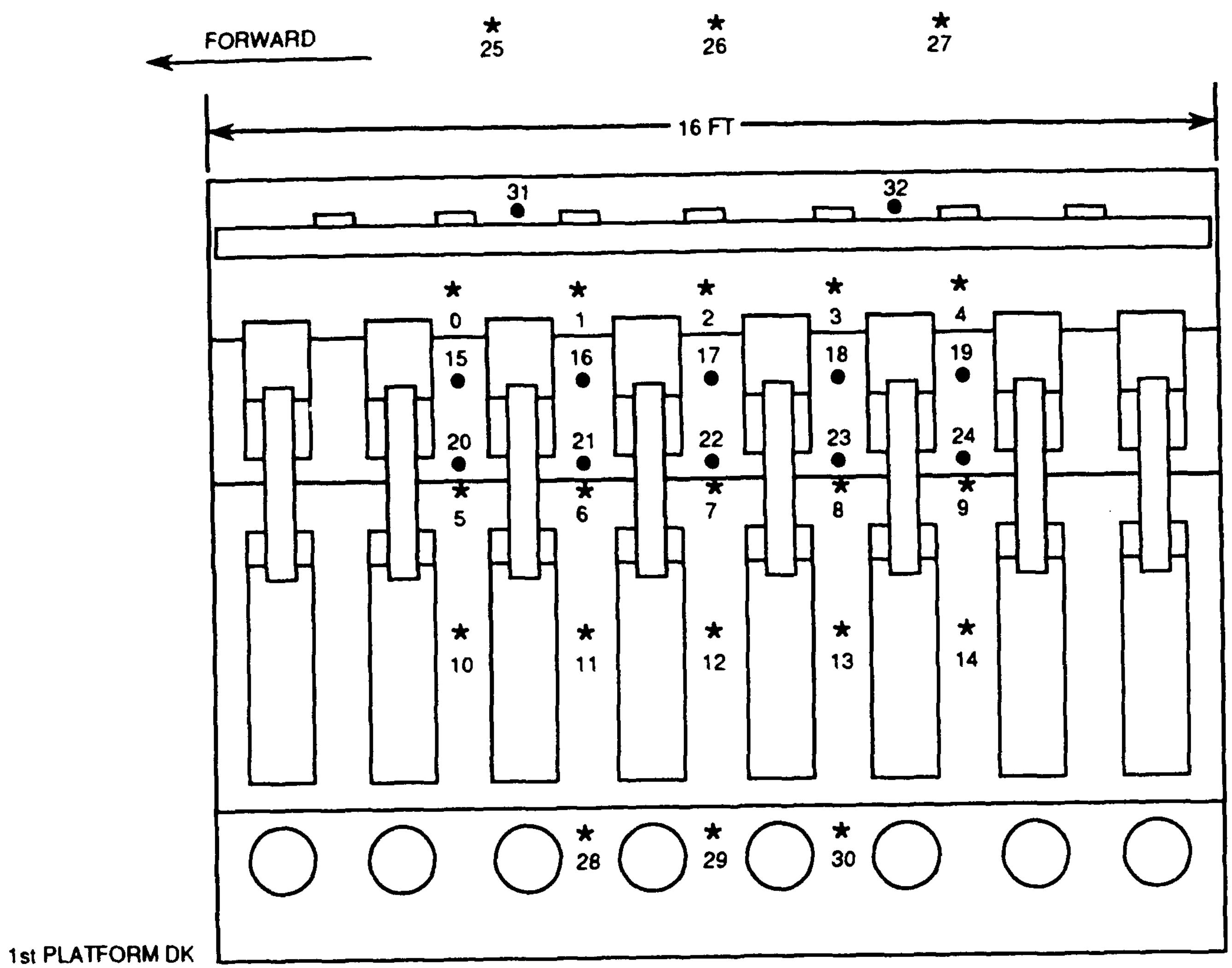

FIGURE A-7 Diesel Mockup Temperature Instrumentation (Side View)

APPENDIX B

Representative Data Plots

The following data plots illustrate the different effects which the carbon dioxide discharges had on the test fires.

Tests on small mockup:

Figure B-1: Fires extinguished in both cylinders (Test SO2A)

Figure B-2: Fires temporarily suppressed (Test SO7A)

Figure B-3: Fires unsuppressed (Test SO4A)

Tests on large mockup:

Figure B-4: Fire extinguished (Test LO3B)

Figure B-5: Fire extinguished on top of mockup, reflash at bottom (Test LO3A)

Figure B-6: Fire temporarily suppressed (Test LO7A)

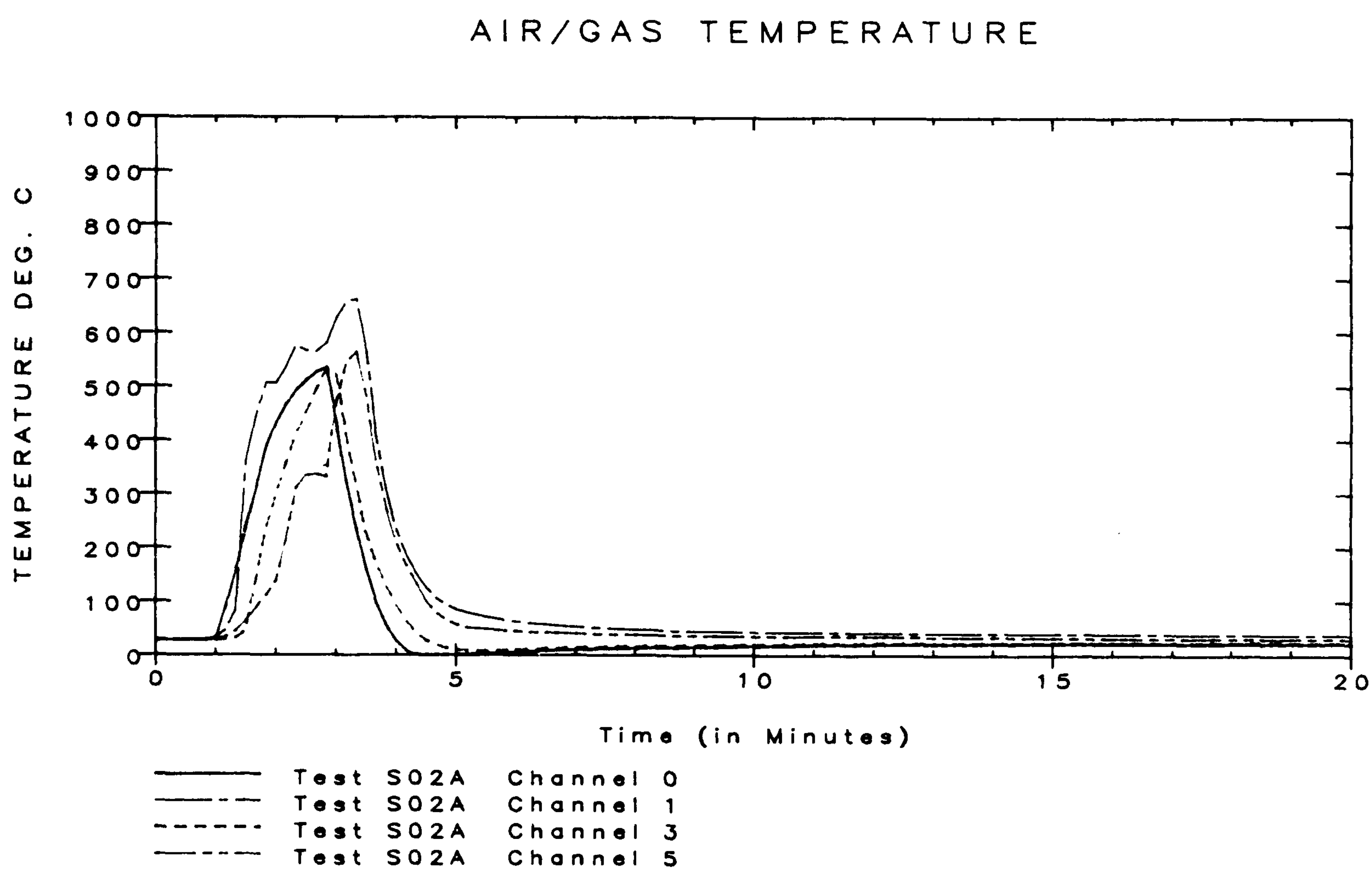

Figure B-1. Fires Extinguished in Both Cylinders of Small Equipment Mockup

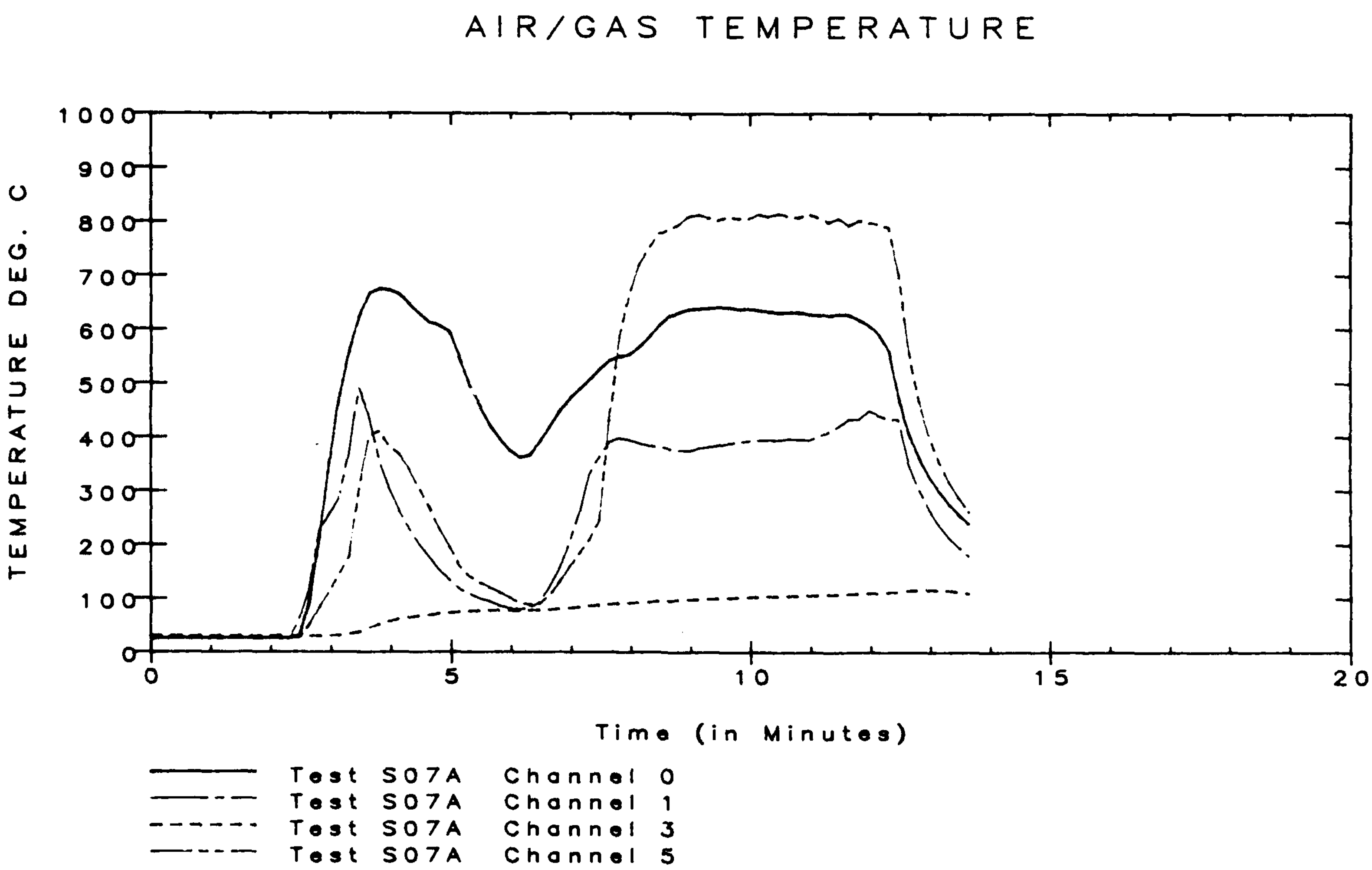

Figure B-2. Fires Temporarily Suppressed in Small Equipment Mockup

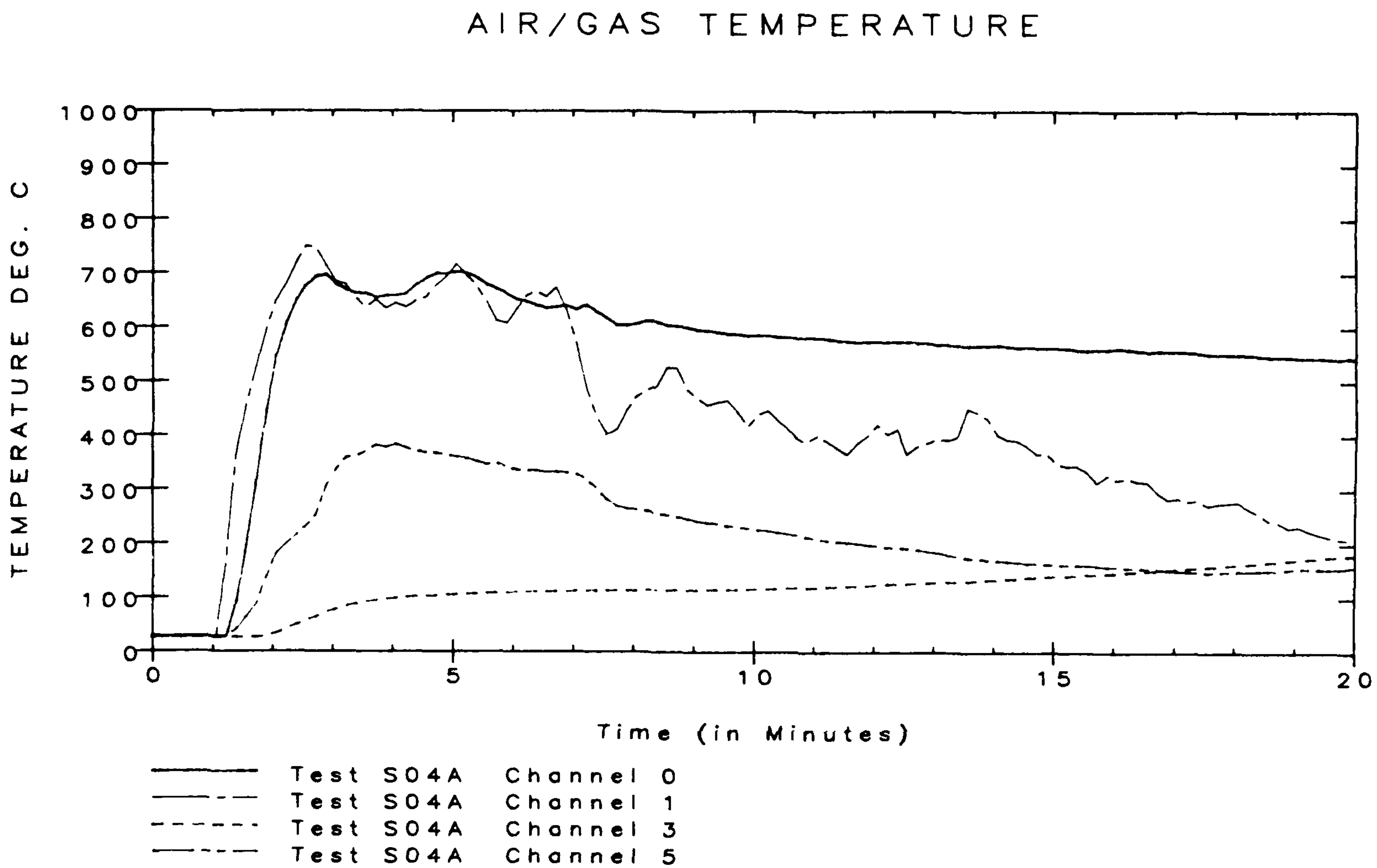

Figure B-3. Fires Unsuppressed in Small Equipment Mockup

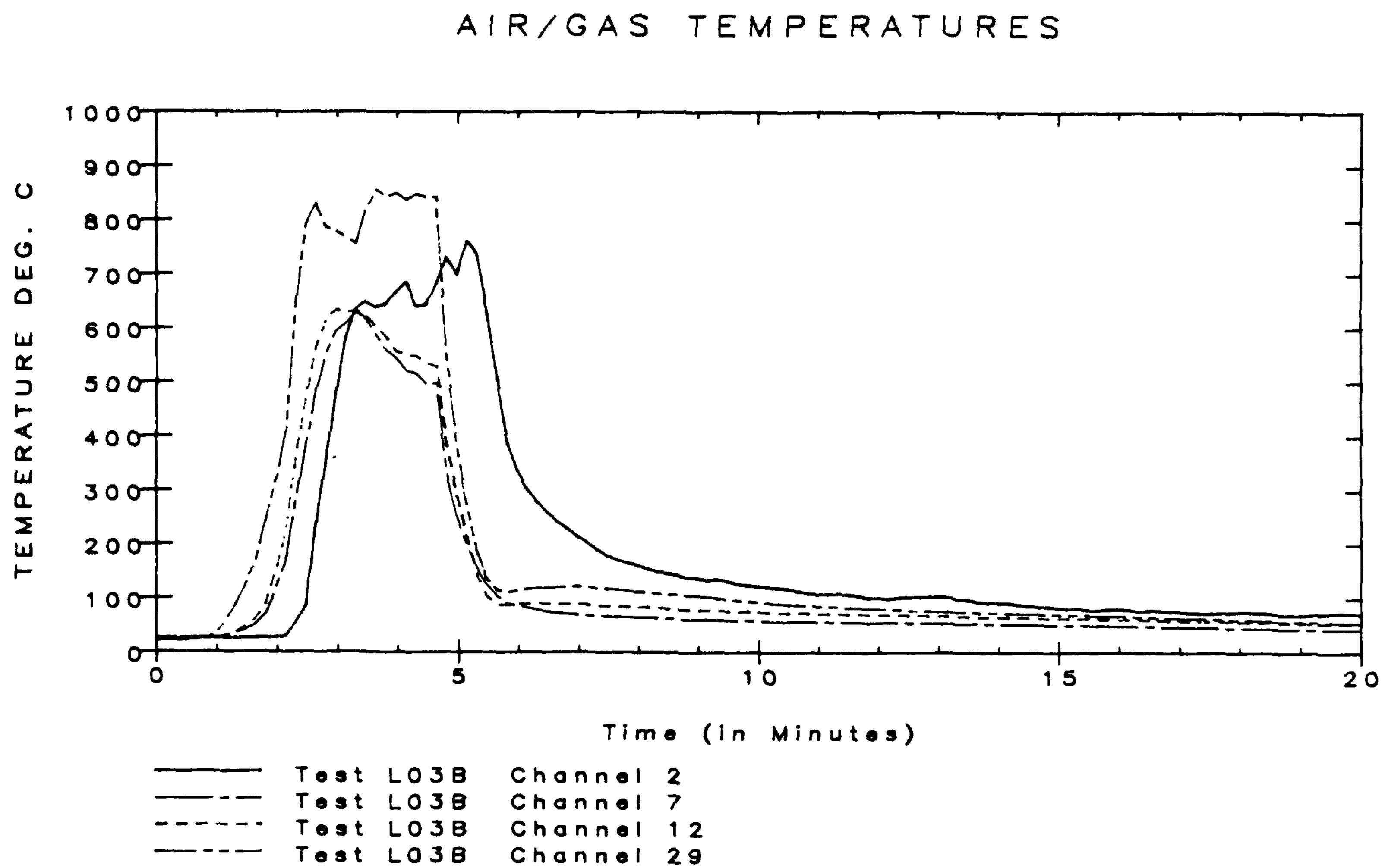

Figure B-4. Fire Extinguished on Large Equipment Mockup

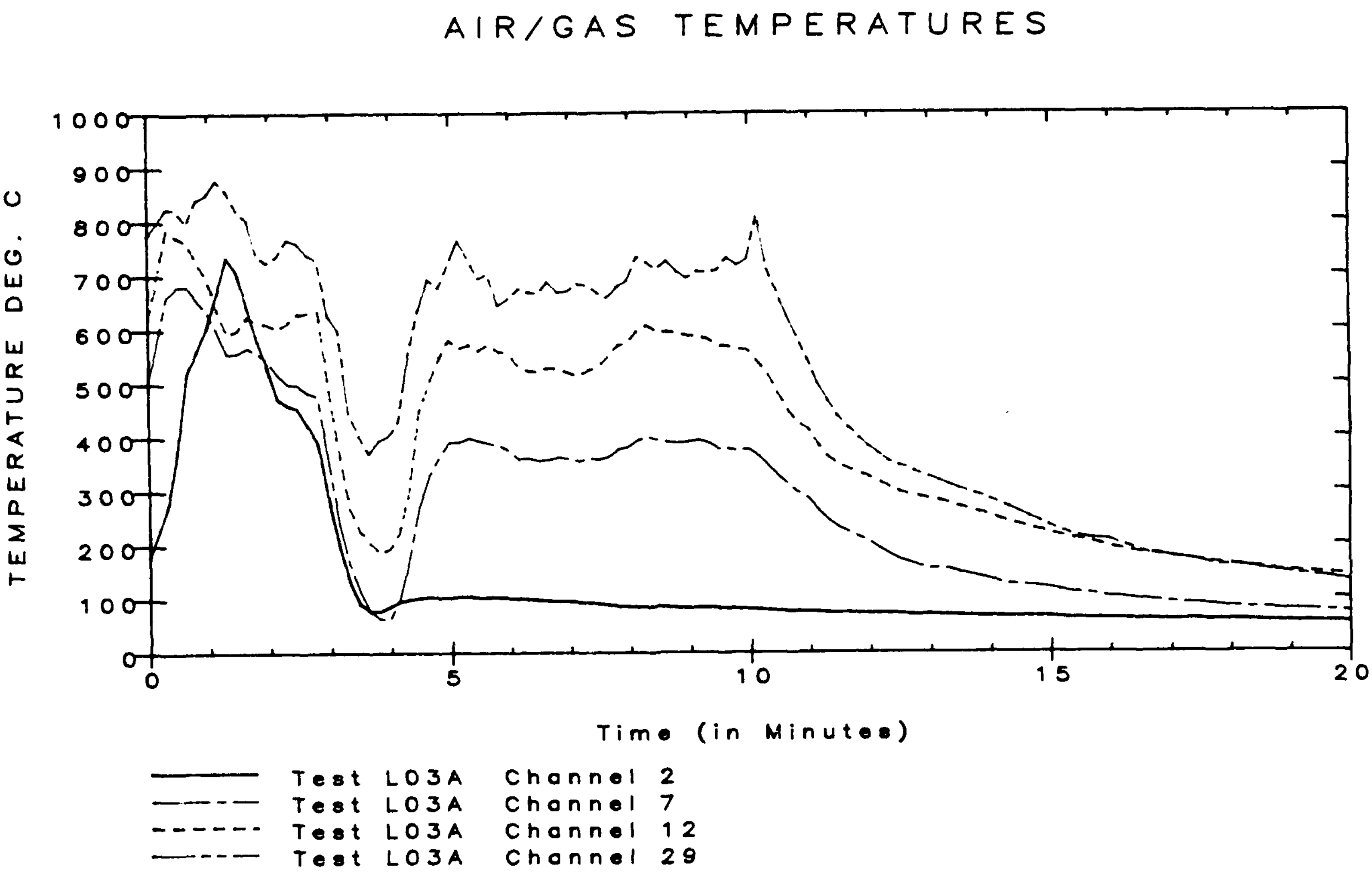

Figure B-5. Fire Extinguished on Top of Large Equipment Mockup, Reflash at Bottom

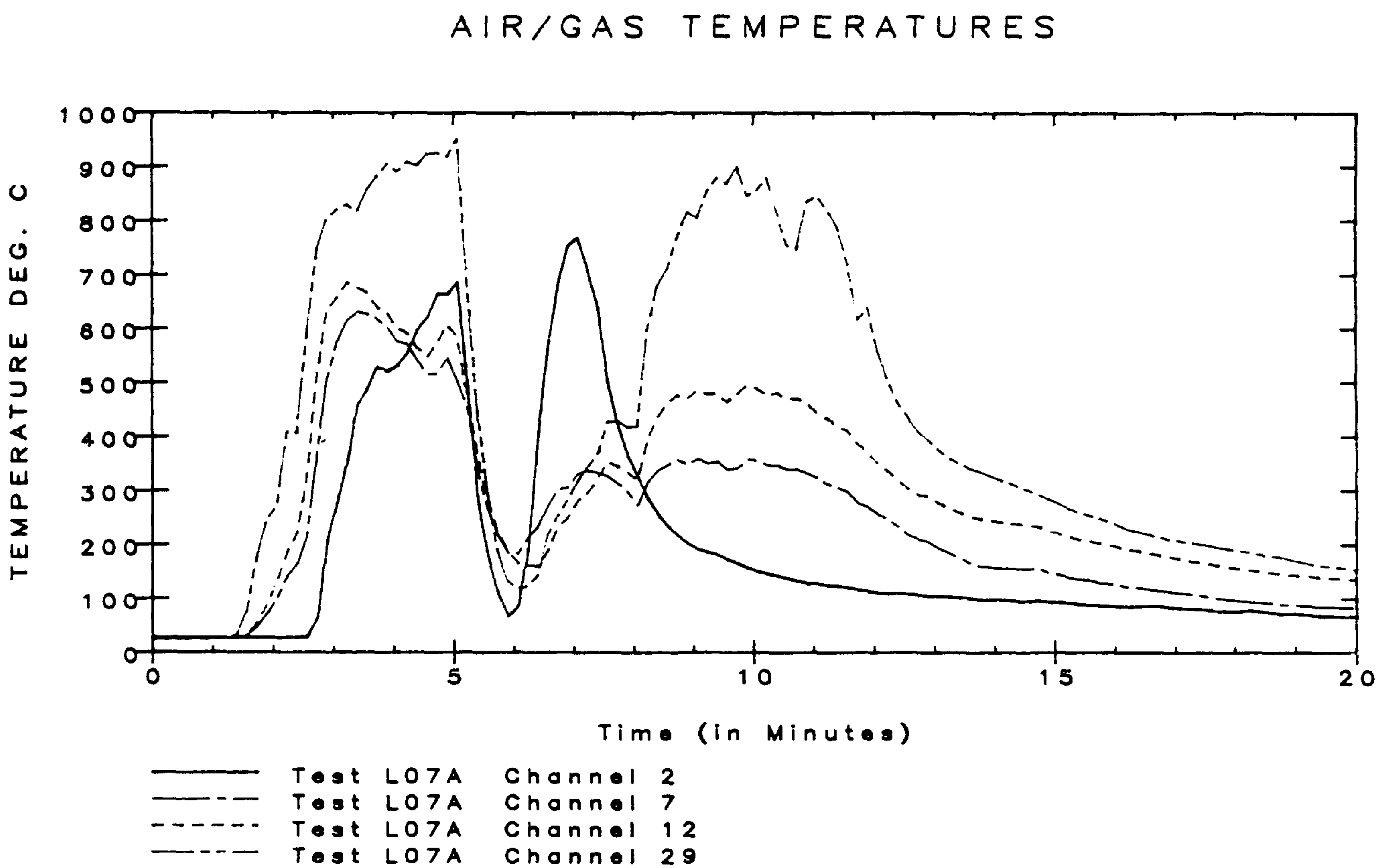

Figure B-6. Fire Temporarily Suppressed on Large Mockup